Clean Energy Systems

Tri-Service Power Expo 2003

Norfolk Waterside Marriott

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Mobile Propulsion and Fixed Power Production with Near-Zero Atmospheric Emissions

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Clean Energy Systems

Needs

- Reliable and secure power supplies for base infrastructure
  - Ideal power is reliable, cost-effective, and low-impact from both size and environmental aspects
- Shipboard power systems for main propulsion, electrical power, catapults, and heating/air conditioning
  - Prime considerations include safety, low life-cycle cost, compact size, ease of maintenance, and fuel efficiency

Clean Energy Systems, Inc. (CE

An advanced technology innovation company, serving the global power market with proprietary zero-emissions processes and equipment

- Founded in 1993 by rocket pioneer Rudi Beichel, co-worker of Werner Von Braun
- Based on technology transfer from aerospace industry
- Emphasizes intellectual properties (twelve patents issued) and manufacturing capability
- Completed testing of 20 MW_t gas generator Feb 03
- Variable 5-15 MW_t gas generator demonstration scheduled Oct 03
- Power plant demonstration 2004

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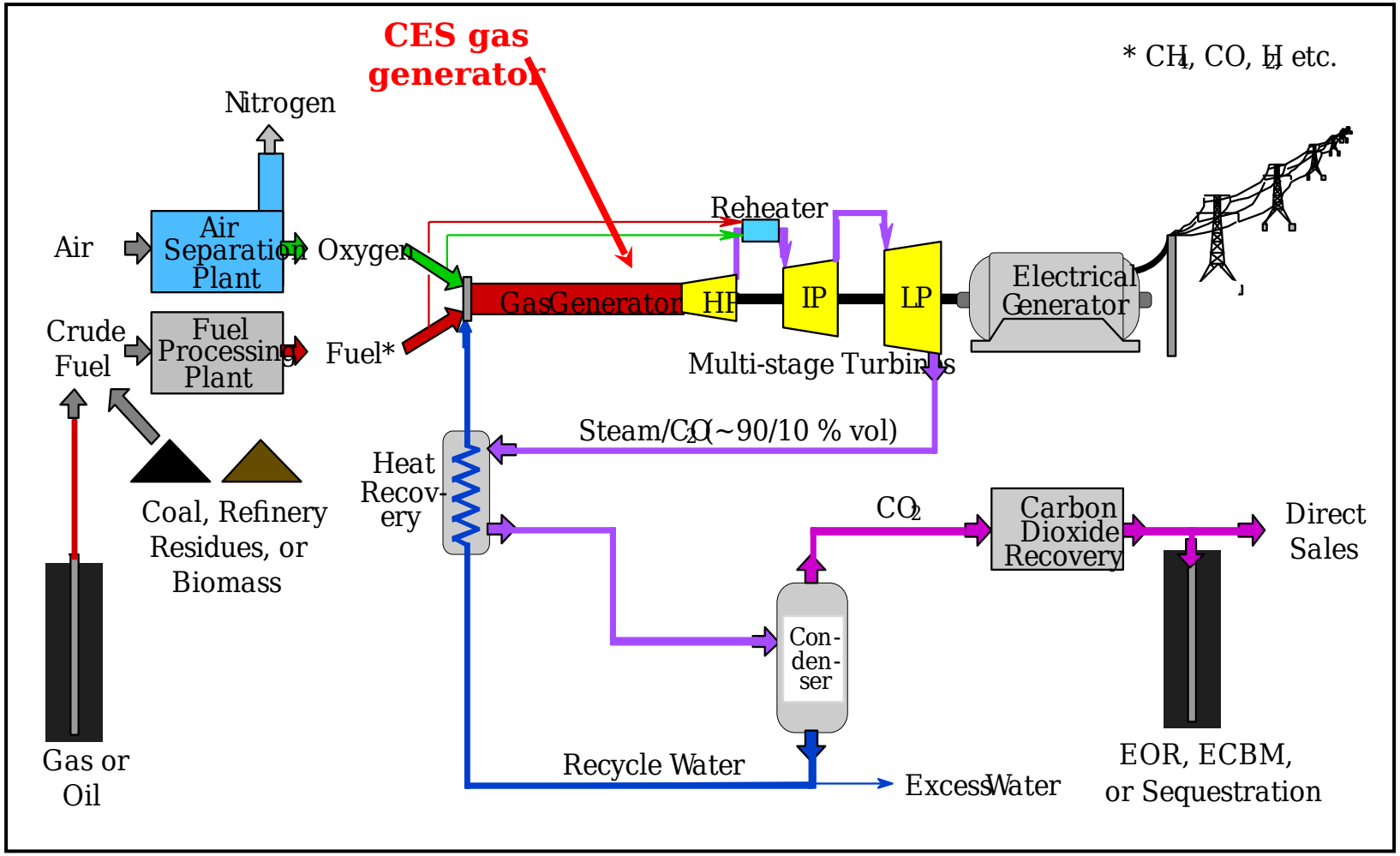
Outline

- Zero-emission power generation process
- The development path
- Results of 20 MW_t gas generator program
- Advanced turbines
- Generation costs
- Shipboard applications
- Fixed-base applications
- Summary

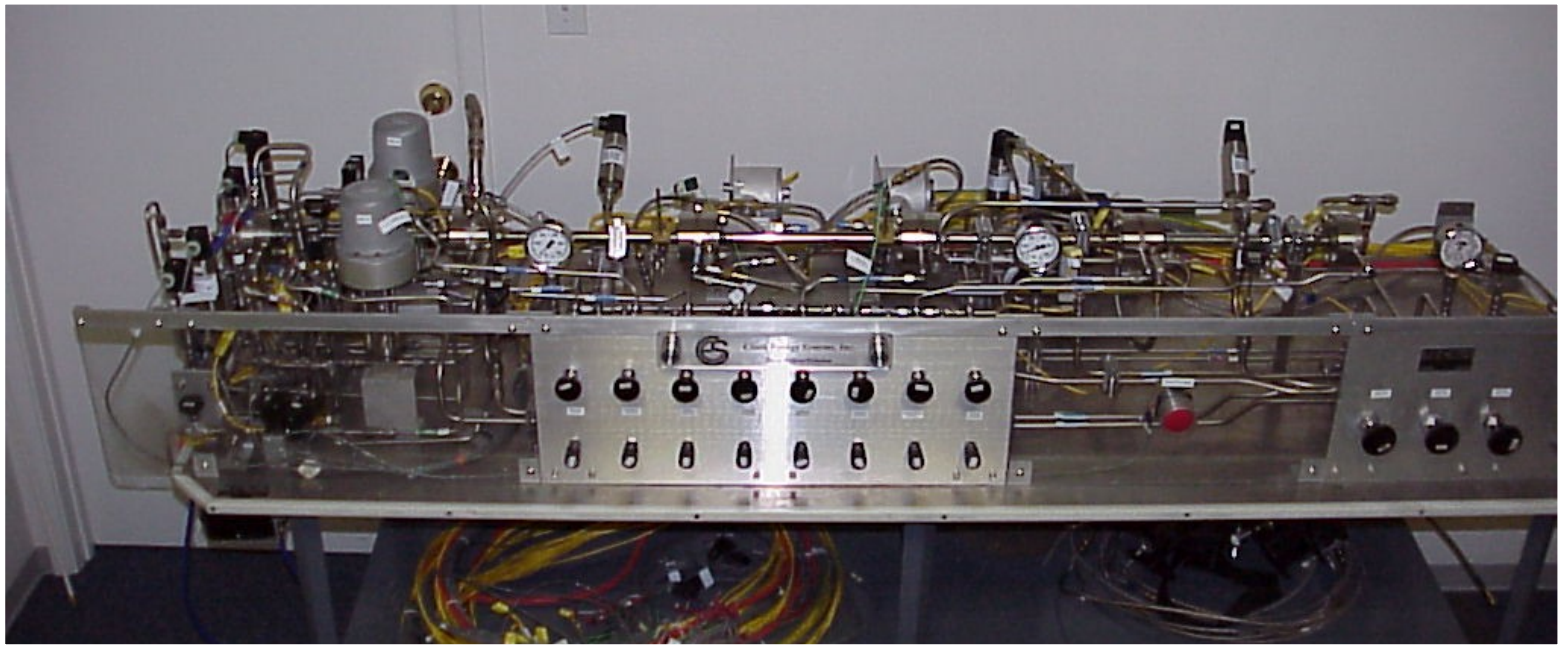
CES Power Process



The Development Path

Lab-Scale Gas Generator Test Program

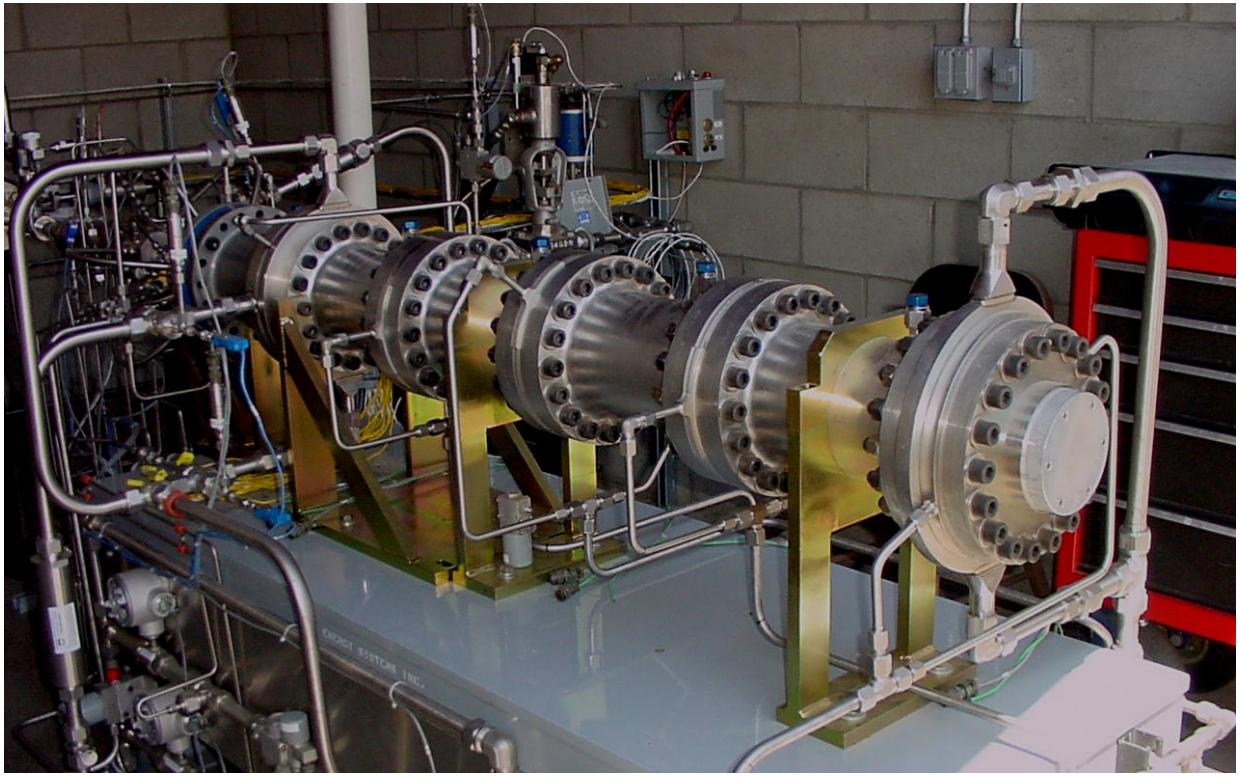
- Partially funded by California Energy Commission
- Testing successfully completed Jan 2001
- Demonstrated “proof of principle” at 110 kW_t scale



The Development Path

Vision 21: Design, Fab, and Test Gas Generator

- Initiated Sep 2000, jointly funded by DOE/NETL and CES
- 20 MW_t Gas Generator, 1500 psia, 1500°F to ~3000°F
- Operates stoichiometrically on O_2, CH_4, and H_2O

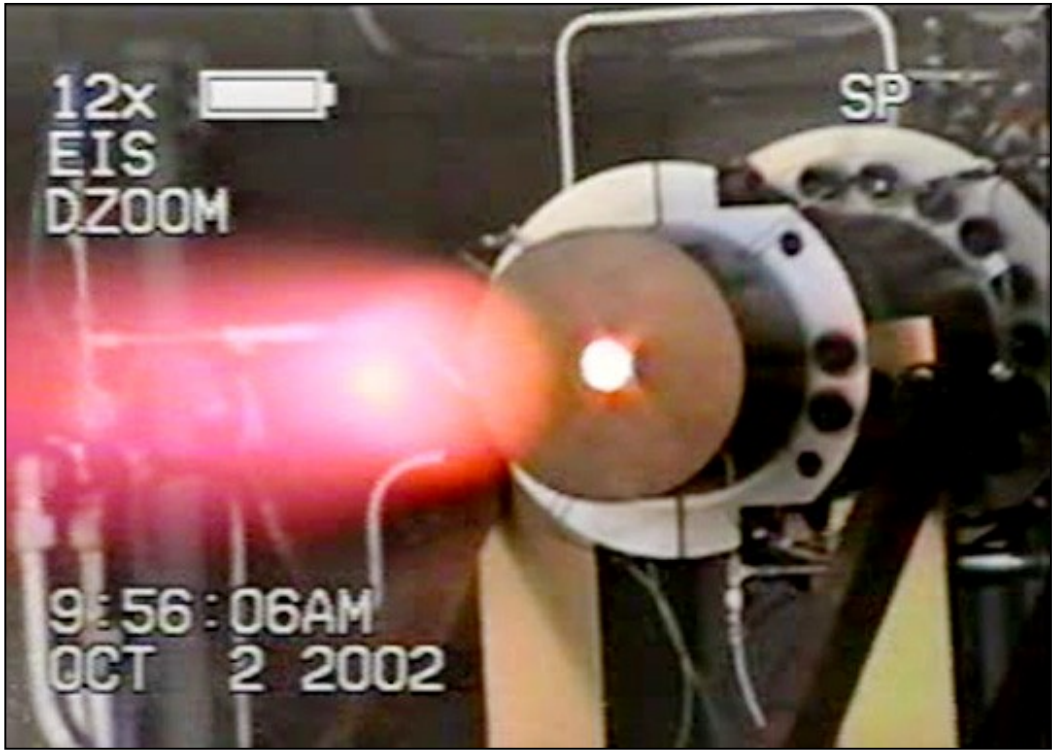


20 MW_t GG Test Results

Uncooled Copper Chamber Tests

- Demonstrated satisfactory injector performance

- Operated at 1560 psia, 2900°F, 33,000 lb gas/hr, and 18.6 MW_t



Uncooled Gas Generator Test – Close View

Uncooled Gas Generator Test – Distant View

20 MW_t GG Test Results

Cooled Gas Generator Tests

- 37 full power tests completed
- Operated continuously to test stand limits (~ 3 min.)
- Accmlt'd 664 sec. test time
- Operated at 1100-1650 psia
- Steam/CO_2 at 600-1600 °F
- Produces ~50,000 lb

3-Minute Test – Close-up View

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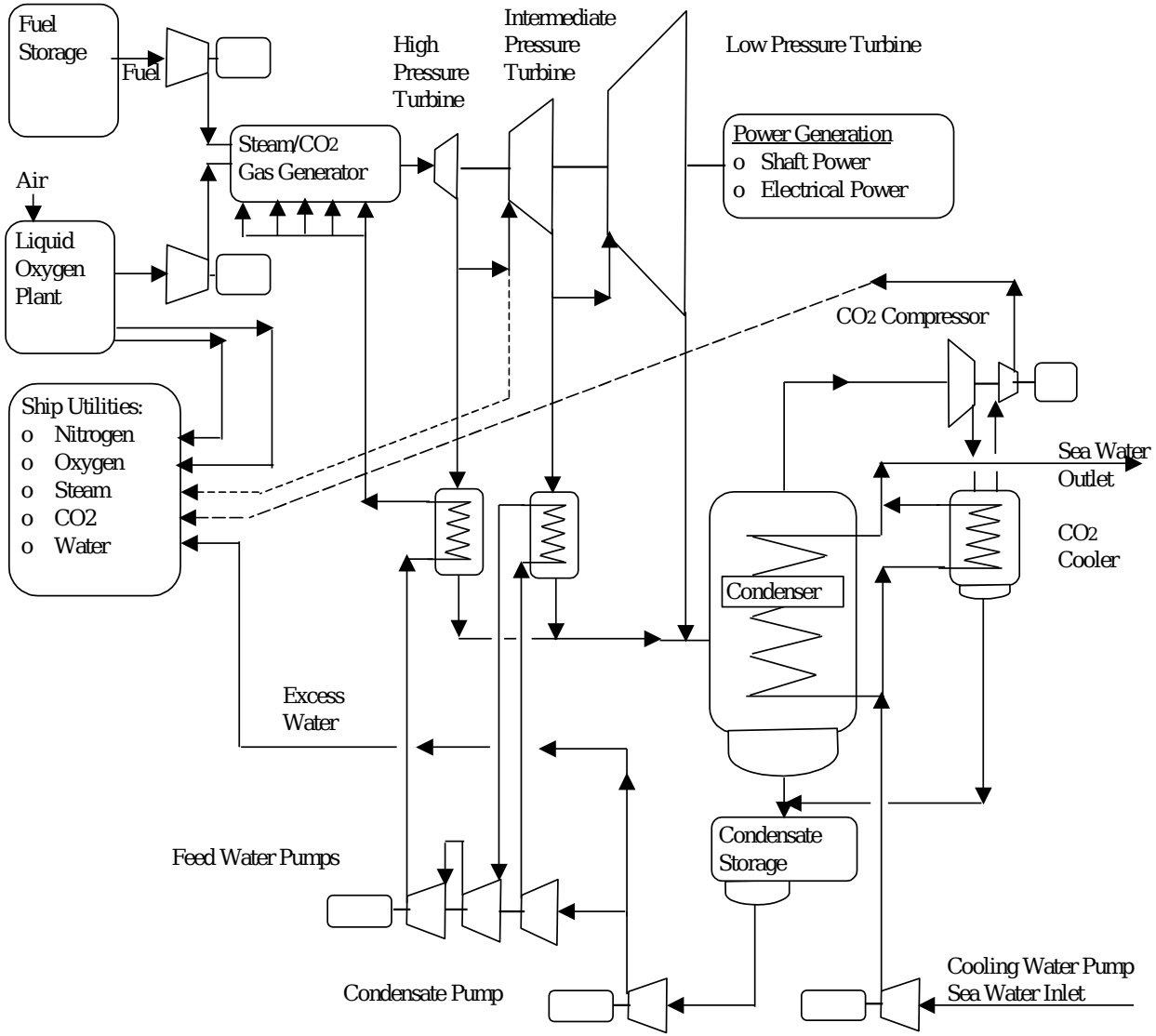
Turbine Technology—Key to Efficiency

Turbine Inlet Conditions→	Current psia — °F	Near-Term (5 years) psia — °F	Advanced (10 years) psia — °F
H-P Turbine	1,200 – 1,050	1,200 – 1,200	1,200 – 1,200
I-P Turbine	170 – 1,050	275 – 2,300	275 – 2,600
L-P Turbine	15 – 740	15 – 2,300	15 – 2,600
Overall Plant Efficiency	33 %	49 %	54 %

Shipboard Applications

- Compact system provides synergistic power opportunities for naval use—output can be electrical, directly linked to the propulsion system, or both
- Startup and acceleration rate limited by turbine constraints
- Ship's primary thermal signature eliminated—stack gases
- By-products can replace replenishment requirements for many consumables
  - Oxygen—medical, fire fighting, aircrew
  - Carbon dioxide—food preservation, fuel tank inerting, fire fighting,

Naval Process Schematic



Naval Power Plant Performance

- Power Plant Performance Comparison

	LM-2500 Gas Turbine	CES Power System
Net Thermal Efficiency	**37.5** %	**45.9** %
Assumptions		
Turbine Inlet Press (psia)	275	1,200/ 275/ 15
Turbine Outlet Press (psia)	14.7	0.61
Turbine Inlet Temp (ºF)	2,273	1,200/ 2,300/ 1,253
Turbine Efficiency	91 %	90/ 91/ 92 %
Generator Efficiency	98 %	98 %
Pump/Compressor Efficiency	n/a	85 %

Need to assess size vs. efficiency trade-offs

Fixed-Base Applications

- Alternatives to grid power can improve security of power supplies
- On-site power generation facilities….
  - Simplify security and reliability concerns
  - Must meet efficiency and environmental requirements
- CES system benefits:
  - No adverse air quality impact
  - No outside feed-water makeup (power cycle is a net producer of water)
  - Smaller plant footprint
  - Economical CO_2 separation/sequestration
  - ASU by-products (O_2, N_2, and argon) available for local use, if needed

Estimated Electricity Costs

50 Mw_e Plants—Natural Gas and Cryogenic ASUs

Plant Operating Factors	Current CES 50 MW	Near-Term CES 50 MW	Current CCGT 50 MW
Overall Plant Efficiency	33%	48%	52%
ASU Plant Size (metric tons/day)	1,080	720	n/a
Capital Cost ($/kW)	2,000	1,575	$1,379
Natural Gas Cost ($/ MM Btu)	$3.00	$3.00	$3.00
NO_x Emissions (lb/MWH_e)	None	None	0.07
CO_2 Emissions (lb/MWH_e)	None	None	870
Gross Electricity Cost ($/MWH)	0.067	0.050	0.045
Note: CES Plants include cost of ASU and CO_2 capture			

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Summary

- Zero-emission CES power generation system mitigates social and environmental concerns
- Current power generation costs already competitive with renewable energy
- Future costs expected to be competitive with large combined-cycle gas turbine plants as plant sizes increase and advanced steam turbines become available.
- CO_2 can be readily captured for sequestration or industrial use.